THE

JOURNAL OF GEOLOGY

SEPTEMBER-OCTOBER, 1896.

DRAINAGE MODIFICATIONS AND THEIR INTERPRETATION.[1]

PART II. CRITERIA FOR DETERMINING STREAM MODIFICATIONS.

(1) ALIGNMENT OF THE DRAINAGE AFFECTED BY THE MIGRATION OF DIVIDES.

BEFORE attempting to apply the law of the migration of divides, it is well perhaps to consider how its operation affects the arrangement of the minor drainage lines; and thus become better acquainted with the criteria of change which we may expect to find in the field.

(*a*) *Rectangular arrangement of the drainage lines.*— Here again we must begin with the simplest conditions possible and progress to the more complex. Manifestly the simplest condition we can assume is that of a region so long subjected to base leveling processes that its surface is a plain with but slight irregularities, standing at or near sea level. The strata must be practically homogeneous and horizontal. The first of these conditions insures an equilibrium of the streams,—a perfect inter-adjustment of the branches which is impossible under other than base-leveling conditions. The second eliminates the effect of geologic structures and the varied character of the rocks which almost always exerts an important influence. When the external influence of geologic structure and character of rocks is removed

[1] Published by permission of the Director of the U. S. Geological Survey.

from the question the law of migration of divides will cause modifications in all the streams within the area affected by the uplift or depression. This applies to streams belonging to the same system, as well as those belonging to different systems. and operates as follows: Wherever two streams are contesting for a divide, and the surface is tilted in a direction perpendicular to that divide, the streams located on the side of the greatest tilting will rob their adversaries of the contested ground and the divide will migrate indefinitely, depending upon the amount and continuation of the movement and the size of the opposing streams. Under such conditions the smaller streams will extend their head branches directly toward the line of greatest uplift, and consequently will arrange themselves at right angles to, and flow away from the axis of uplift, or toward the axis of depression. The larger streams which cross the axis, will be variously affected by the movement, depending upon the volume of the stream and the rate of the uplift. If the volume of water is great and the uplift sufficiently slow, the river may corrade its channel as fast as it is elevated, and so maintain its position. If the rate of uplift is more rapid than that of corrasion, the stream will become ponded and probably robbed of a large portion of its drainage basin by a more favorably located rival.

The small branches, having assumed a course at right angles to the axis, will carry their waters away from the axis until they pass beyond the region affected by the tilt, or join some longitudinal stream of sufficient size to have maintained its course despite the uplift.

The major streams tend to arrange themselves parallel with the axial line, hence they will flow approximately at right angles to the minor drainage lines, producing a rectangular system. A large stream flowing originally parallel with the axis will tend to retain this parallelism, unless it is tapped by some lower stream, and in that event the chances are that it will be tapped by a stream flowing perpendicular to the axis, and the major stream will be transferred to a lower course. In no case, unless local obstacles interfere, will the stream pursue a diagonal

course; its constant tendency is toward courses at right angles to, or parallel with the axis. If the movement is enough to give the rocks an appreciable dip, the stream, in corrading its channel, will tend to cut its banks on the lower side, and in doing so will migrate down the slope of the beds, but in all such cases the stream will move as a whole, still retaining its parallelism with the axial line. If the stream flows, in general, parallel with the axis, but in a broadly meandering course, the tilting will give to the stream a tendency to cut off its ox-bows and so straighten its course and at the same time migrate away from the axial line. This change is produced by the retardation of the current in that portion of the bend in which the stream flows toward the axis, and an acceleration in that portion in which the stream flows away from the axis. Figure 9 represents such a stream on a

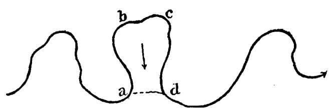

FIG. 9.

surface tilted in the direction of the arrow. In the course *a b* the grade is lessened by the tilting and consequently but little corrasion is accomplished but in the course *c d* the grade is steepened and corrasion is greatly stimulated. As a result of this change in the grade of the stream, the channel at *d* is very much lower than at *a*, hence a small stream may easily work back across the neck of the bend and capture the main stream at the point *a*. This process tends to straighten the course of the stream and at the same time causes it to migrate away from the axial line.

Again the original course of a stream may be neither parallel with, nor perpendicular to the axial line, but may pursue a diagonal course indicated by *A B* in Fig. 10. If such a stream has a branch (*A C*) which flows parallel with the axis, under certain conditions a small branch (*a b*) of the lower stream may cut through the divide separating the two streams and rob the diagonal stream of its upper portion. Ordinarily such a transfer

would probably not take place, for the stream *A B* would probably corrade its channel about as rapidly as the land rose, and so would prevent the lower stream from affecting its capture.

If, however, the arrangement shown in Fig. 10 prevails at the close of a period of quiescence in which the surface is worn down close to baselevel, the streams would be in a position to

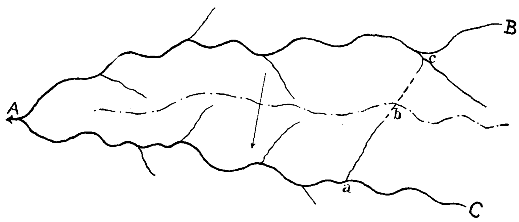

FIG. 10.

take advantage of any opportunity to extend their drainage basins. If at such a time a tilt occurred in the direction indicated by the arrow the point *a* on the stream *A C* would remain at about the same elevation as *A*. The stream *A B* would be accelerated, but active corrasion would, for a long time, be mainly limited to its lower course. The branch *a b* would be greatly accelerated and might be able to cut headwards to the point *c* and capture *c B* before *A B* cuts back to the point *c*. Whether this diversion would be accomplished or not, depends upon the rapidity of the uplift, the volume of water in *A B*, and the character and attitude of the rocks between the two streams.

Thus the migration of divides on a tilted surface tends to produce a system of drainage, the small branches of which are perpendicular to the axial line, and flow in the direction of the dip of the surface; and also a series of branches of the second order, flowing parallel with the axis, and in general coinciding with the downward pitch of the same. When the axis of uplift coincides with a divide already established, it is obvious that the divide will be preserved, but a rearrangement will take place in the head branches of the contending streams. The increased gradient will induce the small branches to extend their upper courses directly toward the axis, and the larger streams will

adjust themselves in a direction perpendicular to the course of the small streams; so the final result will be an arrangement of the drainage similar to that which occurs when the uplift is in any other position.

(*b*) *Unsymmetrical drainage basins.*—When the tilting affects a territory broad enough to include several systems of greater or less extent, a peculiar arrangement is produced which can be

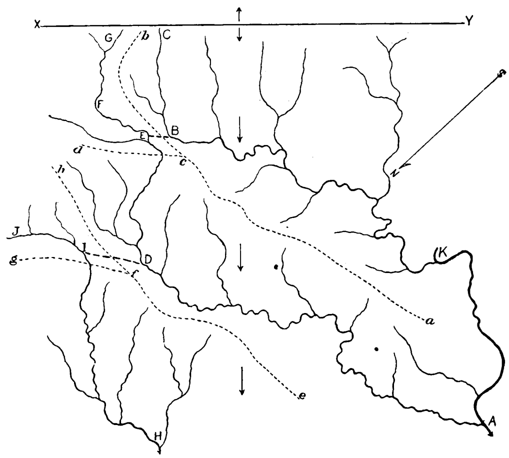

FIG. 11.

easily recognized, and which shows at a glance the direction of the tilt which produced it. The minor drainage lines, as just described, will arrange themselves in general lines at right angles to the axis of uplift, and will unite in trunk streams parallel to the rising fold. Figure 11 represents the drainage on such a broadly tilted surface. The axis is indicated by the line *X Y*. The territory is divided among the streams *A B C*, *A D G*, and *H I J*. It is but reasonable to suppose that before the tilting occurred, these streams were in about the center of their respective basins. As the land rose along the line *X Y* the minor branches on the right-hand side of the larger streams were retarded by the uplift, whereas the branches on the left were accelerated. These accelerated streams crowded the divides farther and farther up the slope and at the same time extended

their head branches directly toward the axis. This produced very unsymmetrical basins in which the trunk streams are flowing on the lower side of the basins, with the minor branches reaching toward the stream next above.

Sometimes these long aggressive tributaries work through the divide and tap the headwaters of the stream next above. In Fig. 11 there are two such cases of robbing; one at the point *E* where the branch *D E* has apparently cut through the divide *c d* and beheaded the stream *A B F G*, and the other at the point *I* where *H I* has robbed *A D I J* of the portion *I J*.

(2) EFFECT OF THE EARTH'S ROTATION ON DRAINAGE LINES.

Kerr[1] observed such an arrangement of the streams of eastern North Carolina, but he attributed their origin to an entirely different cause, viz., the rotation of the earth on its axis. In arriving at this conclusion, he considered the possibility of a tilted surface, but dismissed the idea as untenable. In support of the former hypothesis he cited a few isolated cases which seem to favor his view of the case.

Gilbert,[2] in his study of the effect of rotation, reached the conclusion that the cause is adequate, under favorable conditions, to produce such results, and referred to the drainage of the southern side of Long Island as an illustration of the working of the law.

It is not the purpose of the writer to enter into a discussion of the efficiency of the rotation of the earth in producing drainage modifications of a certain type; but rather to show that such peculiarities are of very common occurrence in places where rotation could hardly have been an active agent, and that some other cause is capable of producing the same effect. As will be pointed out later, changes of just such a character as those described by Kerr in North Carolina and by Gilbert in Long Island can be found in almost every stream of the Appalachian

[1] Geology of North Carolina, 1875, by W. C. KERR, pp. 9–12.

[2] The Sufficiency of Terrestrial Rotation for the Deflection of Streams. Am. Jour. Sci., Vol. XXVII, pp. 427–432.

region. These streams instead of showing the regularity in direction which would be expected if the cause is the rotation of the earth, exhibit an irregular arrangement which clearly indicates that the cause is local and not general. As will be shown later these modifications have a certain definite relation to the great uplift along the Appalachians and seem without much doubt to owe their origin to the tilting which accompanied this uplift. The writer would also suggest that even in the coastal regions there may yet be found evidence of decided elevation, or tilting, of which the visible coastal sediments give no indications.

We have then two theories to account for this class of facts : terrestrial rotation, and the natural adjustment of the drainage upon a tilted surface caused by crustal movements. It has been demonstrated in the previous part of this paper that the latter theory is entirely adequate to produce the given effect, and also that these earth movements have been of frequent occurrence in the past. On the other hand, the sufficiency of the former hypothesis is a matter of doubt, even in the minds of the eminent scientists who have investigated it.

When the practical application of the law of the migration of divides is made, the question becomes very complex. Alternating hard and soft beds, even when they are approximately horizontal, tend to modify the result ; but they are infinitely more potent in shaping the lines of drainage, when they are tilted at various angles, or bent into great folds. At first sight it would seem impossible in such regions to detect any change due to slight surface warpings, but careful study reveals the fact that even here the streams are affected by it, showing by their arrangement the position of the axis of movement and something of the relative steepness of the slopes.

(3) MODIFICATIONS DIFFER ACCORDING TO AGE.

(*a*) *Recent movements shown by barriers and changes of grade.*— The most recent uplifts have not yet affected the alignment of

the streams, for that is a matter of slow development. If the uplift rises athwart the stream, the first recognizable feature is the change of grade in the river profile and the formation of a barrier at the point where the axis crosses the stream. If the stream is flowing over soft, homogeneous rocks, corrasion may take place so rapidly that no appreciable barrier is produced, but as a rule we may expect to find some feature characteristic of a revived stream at this point and ponding in the stream above the barrier.

(*b*) *Remote movements shown by the arrangement of the minor drainage.* — Movements which occurred in the remote past have left no record where they crossed large streams, unless the movement was so severe as to cause reversal but the minor drainage lines may be marked by all of the characteristics described in this paper. The divides may have migrated until all of the stream basins are unsymmetrical, having the main stream near one side and the minor drainage lines reaching out toward the axis of uplift. Unless counteracted by geologic structure, the rectangular arrangement of the drainage lines will be permanent, so long as the crustal movement continues, or until counteracted and obliterated by reverse movements. In such cases if the change has not progressed too far it is generally possible to find cases of stream capture and other marks of radical rearrangement.

(*c*) *Very remote movements shown by the arrangement of the trunk streams.* — As we go farther and farther back into the past, the evidence becomes less and less perfect, until at last it is only in the arrangement of the great streams that we can find a trace of the conditions then prevailing. This of course is unsatisfactory, since it is bare of all details, but in a broad way it outlines the movements which shape the main drainage-ways of that distant age.

(4) PERIODICITY OF STREAM CHANGES.

There is another point which it is well to consider in the application of the law of the migration of divides, and that is,

that the changes induced in the drainage systems are inclined to be periodic in their occurrence. This is extremely important, since it enables us to locate in time many of the changes which otherwise we would be unable to fix definitely.

Streams are so susceptible to prevailing conditions that they do not always respond to the tilting of the surface. There are times when a tilt produces but little effect; then again a slight movement will produce the most profound modifications. If the tilting occurs while the streams are in their youth, it will have but little effect upon them unless it is excessive. In that period of its existence the stream is active, it is cutting its channel vertically, and it is well entrenched in its position, hence a slight tilt of the surface will produce no appreciable effect. If the streams are in their old age, the surface of the land will constitute a peneplain, and if in extreme old age, this peneplain will approach very closely to baselevel. At such times the drainage basins are delicately balanced against each other; not alone are the systems so balanced, but each individual stream is pitted against its neighbors in a balance so delicate that the least outside influence may turn the scale, and the favored stream conquer the ground now occupied by its neighbors. It is at such times that crustal movements are accompanied by the most profound results; consequently we find that a large majority of the changes in the alignment of the drainage systems of the Appalachian region have occurred after a period of extensive baseleveling; they were caused by the first movement which terminated the quiet of the long period of uninterrupted erosion.

(5) CRITERIA FOR DETERMINING THE COINCIDENCE OF LINES OF UPLIFT WITH PREËXISTING DIVIDES.

Since, under favorable conditions, the final result of all long-continued local uplifts has been the migration of the divides to the axial line of the uplift, it would seem difficult, if not impossible, to establish criteria by which to separate the uplifts which originally coincided with divides, from those which were differently located. In a measure this is true, but there are certain

characteristics which seem to mark such uplifts and separate them from the general class.

If a drainage basin, having a long circuitous outlet to the sea, or one which is greatly retarded in its development by hard rocks, maintains its balance against an opposing stream having ready access to the sea, it is altogether probable that this balance has been maintained by an uplift which corresponded originally with the divide between the basins.

PART III. APPALACHIAN DRAINAGE.

The preceding portion of this paper has been devoted to the demonstration of the law of the migration of divides, and in presenting the criteria by which such changes in the drainage systems may be recognized. These criteria are divisible into three classes, indicative of different degrees of change, as follows:

Class 1.—Barriers or obstructions in the channel of a large stream with attendant features which are indicative of very recent movement,—so recent indeed as to have no effect upon the alignment of the stream or any of its branches.

Class 2.—Complete rearrangement of the minor drainage lines. This points to a pronounced warping at a time so remote that all of the lesser streams have become adjusted to it by changing their courses as previously described.

Class 3.—Certain arrangement of the trunk streams, indicative of crustal movements of pronounced character and of very ancient date.

It now remains to examine hastily some of the drainage systems of the United States, to see if we can detect any of these characteristics. In so doing, attention will be confined almost exclusively to the region east of the Mississippi River, as being the one with which the writer is most familiar; and in this Appalachian region we shall consider only that portion which is south of the great terminal moraine, for in glaciated regions the problem of stream modifications is entirely too complex for present consideration.

(1) RECENT MOVEMENTS INDICATED BY THE MUSCLE SHOALS IN THE TENNESSEE RIVER.

The Tennessee River is obstructed, in its course through northern Alabama, by a barrier which is widely known as the Muscle Shoals, and which has been, until the completion of the canal in recent years, a serious bar to the navigation of the stream. In this case there is no possibility of the existence of an old, abandoned channel around the obstruction, such as characterizes the falls of the Ohio River at Louisville, Kentucky. The Tennessee River at the Muscle Shoals is occupying the same channel that it did in late Tertiary time, hence the obstruction in the stream must be accounted for by some hypothesis which admits of the occupancy of the present channel for an indefinitely long time.

Such a barrier can be produced in one of two ways: either the entire region has suffered an uplift and the river has only succeeded in cutting its channel back to Florence, Alabama, or a local uplift has occurred at this point which has elevated a small portion of the stream above its normal grade, and this uplift has been so recent that the stream has not yet been able to remove the barrier. In order to determine which hypothesis best accounts for the facts, it will be necessary to examine closely all of the characteristics of the stream both above and below the barrier.

(*a*) *Profile of the Tennessee River.*—From Chattanooga, Tennessee, to Brown's Ferry, Alabama, a few miles below Decatur, there is a fall of but 49 feet in 185 miles; below Brown's Ferry for a distance of 57 miles the descent is rapid, amounting to a total of 169 feet; below this the grade is again slight, having a fall of only 120 feet in 250 miles.

From these figures it is apparent that there is not only a break in the grade, but also that the elevation of the head of the shoals is above the average grade of the river from Chattanooga to its mouth. This evidence appears to favor local uplift, but it is not conclusive.

(*b*) *Character of the river valley.*—From South Pittsburgh, Tennessee to the head of the shoals, the valley of the Tennessee River is broad and worn down about to the baselevel of the stream at the head of the shoals. Reliable data concerning the character of the valley below the shoals are difficult to obtain, but the preponderance of evidence seems to show that this also is a rather old valley, with all of the side branches cut down to the level of the river. From this it appears that the valley below the shoals is fairly comparable in age and amount of excavation to the valley above the shoals, and that both have the appearance of considerable age. Between these two old portions of the valley lie the Muscle Shoals in which active corrasion is going on today. This result could not have been produced if the region had suffered general elevation alone; hence the question is narrowed down to the theory of a local uplift.

(*c*) *Character of the stream.*—Since the rocks composing the shoals are the hard, cherty beds of the lower Carboniferous, we should expect to find some evidence of ponding above the shoals, if they were caused by a local uplift. According to the Huntsville sheet of the United States Geological Survey and the description given by the Army Engineers[1] who made the survey of the river there are distinct traces of ponding from Brown's Ferry to a point south of Huntsville. All of the phenomena associated with the Muscle Shoals point to a recent and local uplift as the cause of the barrier.

There are many other streams in the Appalachian region which show barriers and gorges of quite recent construction, but in most cases they are due to a general elevation which has simply produced a revival of the stream. A critical study of these obstructions fails to reveal the characteristic features found in the Tennessee River at the Muscle Shoals.

(2) REMOTE CHANGES SHOWN IN THE STREAMS OF THE MISSISSIPPI VALLEY.

The adjustments of this order are confined to the rearrange-

[1] Report of the Secretary of War, Vol. II, 1868–69, p. 584.

ment of the minor drainage lines, hence a study of these will be best facilitated by an accurate drainage map.

Numerous cases of such adjustments can be found in the streams of the Mississippi Valley, where the general horizontality of the rocks keeps the problem free from great complications. In this region we find many cases of the migration of divides and the complete rearrangement of the drainage lines.

(*a*) *Kanawha River basin.*—A noteworthy case of this kind, occurring in the central portion of West Virginia, is shown in Fig. 11, and has been described in the previous portion of this paper as a type example of its kind. *A K* (Fig. 11) is the Kanawha River, *K B C* is the Gauley River, *A D G* is the Elk River, and *H I J* is the Little Kanawha River. The first two streams belong to the Great Kanawha system and the last to the Little Kanawha or Ohio River system. As previously explained, the divides have migrated toward the southeast, until in places they are within a mile of the stream next above. It will be noticed that this action is much more effective near the heads of the streams, for at this point alone has capture resulted. Lower down, the divide still remains close to the stream above, but diverges more and more until, as it approaches the mouths of the streams, it is about equally distant from the stream above and the stream below. This is doubtless due to the fact that most of the shifting occurred when the region was uplifted and tilted, after the cutting of the extensive peneplain which is a marked feature of the region. The large volume of water in the lower courses of these streams enabled them to maintain their former courses and quickly intrench themselves within the tilted plain. Since then their cutting has been so rapid that it has overbalanced all of the effects of the tilt; consequently their basins, in this portion of their courses, are approximately symmetrical. Farther up the streams, where the volume of water was less, the streams were unable to so fortify themselves, and consequently were dispossessed of most of their territory by their lower neighbors. At their extreme heads, the streams were held for a long time on the surface of the peneplain, and

the tilting exerted its full force in producing a rearrangement of the drainage lines. The result of this exposed condition is that most of the streams have been captured by branches working back from the northwest producing the imbricated arrangement shown in Fig. 11.

In the light of the previous discussion, there seems to be no question that this condition is due to a gentle tilting of the surface toward the northwest from near the Greenbrier River. In this region the inter-stream areas are of such an elevation that the principal migration must have occurred long ago—when the general surface was many hundreds of feet higher than today, and at a time when the surface relief was slight. There were probably two periods when such a change could have taken place, contemporaneously with the completion of either the Cretaceous or the Tertiary peneplains. The character of the changes point rather to the latter than to the former; for if the tilting had occurred in Cretaceous time, subsequent changes would, in all probability, have obliterated the courses of the minor streams. But it is the minor drainage lines which are here the characteristic features and which were probably formed long after the uplifting of the Cretaceous plan from baselevel.

(*b*) *Big Sandy and Clinch River basins.*—Southwest of New River, the streams flowing directly to the Ohio are encroaching upon the streams of the Tennessee system, although the latter has a decided advantage in the soft limestones and shales of the Appalachian Valley. Tug fork of Big Sandy River has cut entirely across the coal field, and its head is within a mile of Clinch River at a point fifteen miles below the source of the latter.[1] Not only has it encroached to within such a short distance, but it is flowing more than 300 feet below Clinch River at the point of its nearest approach. In its backward cutting it has reached the Valley limestone and, if conditions remain unchanged, it will be but a short time, geologically speaking, until it will capture Clinch River at this point. The migration of this divide is in the same direction as the cases already cited and is evi-

[1] See the TAZEWELL Atlas sheet of the U. S. Geological Survey.

dently the result of the same cause. This is doubtless the uplift already described by C. W. Hayes and myself;[1] an uplift which accelerated the northwestward flowing streams, but retarded Clinch River by crossing that stream some distance below its source.

(*c*) *River basins of Kentucky.*—The state of Kentucky, lying almost entirely within the undisturbed region of the Mississippi Valley, presents a fine field for the study of drainage forms. A glance at the map of the state shows that even in that region of nearly horizontal rocks the drainage is not well balanced, the stream basins are not symmetrical, and the divides are apparently migrating. Shaler recognized these peculiarities, but he was unable to offer an adequate explanation. He writes as follows:[2] "It is not easy to account for this irregularity in the disposition of the streams away from the mountain regions. Away from those disturbed regions there are only slight irregularities in the rocks, which do not seem to have any power of determining the range of a river basin." He then suggests that their peculiarities may be inherited from conditions in previous ages, when the distribution of hard and soft rocks was very different from that which prevails today.

In the light of the present study, the arrangement of the drainage lines of Kentucky is not peculiar; in fact much of it is most natural and what we would expect, if the surface slopes from the interior toward the Ohio River. The divide on the north side of Cumberland River is apparently encroaching on that stream under an influence similar to that which permits Big Sandy River to encroach upon Clinch River. This encroachment is so pronounced that at one time it was proposed to divert the waters of the upper Cumberland into Goose Creek, a branch of the Kentucky River. The headwaters of Green River also are crowding back toward the southeast against the Cumberland basin and have now approached to within a very few miles of the main river. These divides must have migrated toward the

[1] Geomorphology of the Southern Appalachians, Nat. Geog. Mag., Vol. VI, p. 94.

[2] Kentucky Geological Survey, Vol. III, New Series, p. 360.

latter stream, hence we conclude that the prevailing tilt of the surface has been toward the northwest and away from the Cumberland River.

Some of the peculiarities cannot now be satisfactorily explained even on this basis, but the writer believes that it is because of the lack of reliable data and of the complexity of the problem. They are doubtless due to the same cause, but in all probability it has not always acted in the same place, nor in the same direction.

(3) REMOTE CHANGES SHOWN IN THE STREAMS OF THE ATLANTIC SLOPE.

Throughout the gulf coast of the Atlantic slope there are numerous examples of migration of divides and the consequent unsymmetrical condition of the stream basins. The limits of this paper will not permit of a full discussion, so only a few can be mentioned.

(*a*) *Chattahoochee River*.—The most pronounced case of the kind is the encroachment of the Atlantic streams upon the Chattahoochee River. From Columbus, Georgia, to its headwaters, the drainage basin of this river is limited almost entirely to its northwestern side. Figure 12 shows the arrangement of the drainage lines in the region about the headwaters of the Chattahoochee River. *A B* is the Etowah River; *C D*, the Chattahoochee River; *G*, the Oconee River; *H*, the Broad River; and *K L*, the Savannah River. The Atlantic streams, or those flowing toward the southeast, have symmetrical basins in which are developed beautiful dendritic drainage lines. The small branches are numerous and have straight, regular courses at right angles to the main line of the Chattahoochee River This arrangement of the minor drainage lines is indicative of a strong southeastward slope of the surface. These minor streams have not only arranged themselves parallel with the line of greatest slope, but they have also extended their courses headwards, until at one point they are within a mile of the Chattahoochee River and at least 100 feet below it.

At this point, which is in the vicinity of Gainsville, Georgia, the capture of the Chattahoochee is imminent, and if conditions remain unchanged, will doubtless be accomplished in the near geologic future. In the vicinity of Tallulah Falls the same process has been carried on, but in this case it has reached completion, and the Savannah River has cut through the divide and

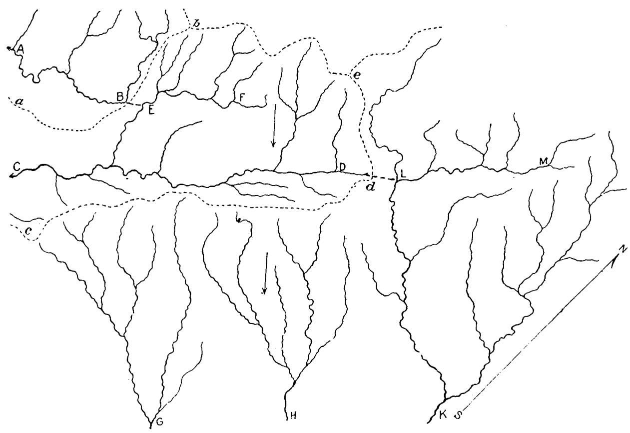

FIG. 12.

captured the portion *L M*, which formerly constituted the headwaters of the Chattahoochee.

The minor drainage lines in the Chattahoochee basin have also arranged themselves parallel with the line of greatest slope of the surface. They, in turn, are encroaching upon the drainage basins to the northwest, although their headward progress is greatly retarded by the mountainous character of the divide upon which they are encroaching. At the point *E*, however, a small branch of the Chattahoochee has already succeeded in capturing the stream *E F*, which doubtless previously belonged to the Etowah River.

This example is somewhat complicated by complex geologic structure, but the arrangement of the minor streams across this structure appears to be evidence of even a more pronounced tilting of the surface than that which has caused such a radical

rearrangement of the drainage in West Virginia. The fact that the extreme head branches of the Atlantic streams have been enabled to cut below the bed of the Chattahoochee seems also to show that these streams have had a decided advantage since the elevation of the Tertiary peneplain to its present altitude.

(4) REMOTE CHANGES SHOWN IN THE STREAMS OF THE APPALACHIAN VALLEY.

So far we have considered only those cases in which geologic structure has played little or no part in shaping the courses of the streams. While in such cases the effect of surface tilting is most pronounced, it has also operated in the Appalachian Valley where geologic structure dominates the whole topography.

No one can consider for a moment the drainage basins of the Susquehanna, Potomac, James, and Roanoke rivers without being impressed by their unsymmetrical condition. In the case of the Roanoke and New rivers, there can be no doubt that the former is encroaching upon the grounds of the latter. This is so apparent that a traveler on the railway easily distinguishes the difference in grade on the two sides of the waterparting between them. In this case, although the divide may now be migrating toward New River, it is very certain that this has not continued for a long time, else New River would have been captured long ago. Here we are not concerned about the migration of the divide, but rather about its non-migration. Since for a long time, New River must have been working at a great disadvantage against Roanoke River, why has not the latter cut through the divide at Christiansburg and captured the entire head of the former stream?

As has been explained, the preservation of a divide under unfavorable circumstances is no more anomalous than the migration of a divide toward the axis of uplift; it simply indicates that the unfavorably located stream has been assisted in the preservation of its drainage basin by an uplift which corresponded with the preëxisting divide between the contending streams; and which by its continued movement has prevented the aggressive stream from absorbing its weaker neighbor.

The constantly increasing magnitude of the river basins in the Appalachian Valley from New River to the Susquehanna, at once suggests the idea that the northern streams have been more favored in their development than the southern streams, and as a result have grown largely at the expense of the latter. Roanoke River has but a few square miles of its basin within the rocky walls of the Blue Ridge; James River has pushed farther toward the northwest, but is still confined well within the limits of the zone of folded rocks; Potomac River controls much more of the area in question and is practically limited in its northwestern side by the Alleghany front; Susquehanna River has not only gained control of a large portion of the valley, but has also extended its headwaters far back into the Alleghany plateau of western Pennsylvania and southern New York. It is at once obvious that these streams are working under different conditions; and judging from their arrangement, it is probable that much, if not all, of this difference is due to difference in amount of interior uplift, and also to the location of the axis of the movement.

The water parting between the Atlantic streams and those belonging to the Ohio River drainage basin forms a remarkably regular line which crosses the valley obliquely from the Blue Ridge south of Roanoke, Virginia, to McKean county, Pennsylvania. From the criteria already established this would appear to mark the position of an axis of uplift which has been mainly instrumental in shaping the drainage basins on either side.

From the James to the Susquehanna the basins are decidedly unsymmetrical; the divides have migrated toward the southwest, until the divide between the Susquehanna and the Potomac approaches close to the left bank of the latter stream, and the divide between the Potomac and the James allows to the former about twice as great an area as it does to the latter. This migration is certainly due to a tilting of the surface toward the northeast, which favored the development of the Susquehanna at the expense of the Potomac, the Potomac at the expense of the James, and the James at the expense of the Roanoke River.

Examples may be multiplied indefinitely, but enough has been cited to show that Appalachian drainage has all of the marks which theoretically we should expect to find on a tilted surface.

(5) VERY REMOTE CHANGES SHOWN IN SOME OF THE APPALACHIAN RIVERS.

In passing still farther backward in geologic time, the minor drainage ceases to be our guide; and we are limited to the big trunk streams from which to read the history of events. Almost every large stream of the Appalachians gives some hint of the surface conditions under which it was formed.

(*a*) *Chattahoochee drainage line.*— The limits of this paper will not permit the mention of all the probable examples, only a few of the most striking will be given. Perhaps the most pronounced example of the kind, and at the same time one that carries the history back the farthest, is that of a series of streams on the eastern side of the Blue Ridge, the arrangement of which appears to have been determined by the depression which preceded and made possible the deposition of the Triassic sediments of the eastern part of the United States. A glance at a map reveals the fact that the course of the Chattahoochee River above Columbus, Georgia ; the Savannah above Tallulah Falls; the French Broad above Asheville; and the upper portions of the Catawba and Yadkin rivers occupy almost continuously a line from the margin of the Cretaceous sediments of the Gulf coast to the Triassic deposits of the Dan River area. This continuity of drainage lines at once suggests some common cause, for it seems highly improbable that their location along this line was simply fortuitous. According to the principles laid down in the preceding parts of this paper, such an arrangement could have been brought about by a subsidence the axis of which corresponds with the present drainage lines.

(*b*) *Triassic areas in the same line.*— The areas of Triassic rocks in this region are generally regarded as remnants of a more extended deposit which took place in troughs formed by

local subsidences. The remaining areas of these rocks seem to range themselves in two approximately parallel lines. The westernmost line consists of the Dan River[1] and Danville areas, Scottsville and Barboursville areas, and the great New York-Virginia area stretching in an almost continuous line from Germantown, North Carolina to Stony Point, New York. This is the direct continuation of the Chattahoochee drainage line, and, strangely enough, it is apparently continued to the northward by the valley of the Hudson River and Lake Champlain. The easternmost line, consisting of the Wadesboro and Deep River areas, the Richmond area and the Connecticut area, roughly parallels the first, and it has a northward extension in the Connecticut River Valley. Whether or not it ever had a southwestward extension similar to the parallel line cannot now be determined, for post-Triassic erosion and sedimentation have removed all traces of such streams if they ever existed.

These parallel lines are everywhere marked by stream valleys or areas of deposition, therefore by our criteria they should mark the axes of parallel depressions. These depressions seem to have reached their maximum near the center of the line, for in this portion the sediments probably formed a continuous sheet, indicating that the old land surface had sunk entirely below water level. This maximum submergence appears to have been along a cross axis, or one extending in a northwest and southeast direction; and to this cross depression is probably due the location of the Susquehanna River, the largest and most vigorous of the central Atlantic streams. Judging from the direction of the flow of the streams located along the longitudinal axis, it seems probable that the depression reached a minimum at the southern line of North Carolina, for at that point the waters divide toward the southwest and the northeast.

If our interpretation is correct, these are some of the oldest streams in the United States. With the one exception of the upper portion of Savannah River, which formerly belonged to the

[1] The names of the various areas of Triassic rocks are taken from Correlation Papers — The Newark System, by I. C. Russell, Bulletin No. 85, United States Geological Survey.

Chattahoochee system, it seems probable that they have persisted in the course then determined up to the present time. This interpretation also presupposes the existence of a peneplain at the time the depression occurred, for with the present rugged topography along this line almost no amount of tilting could produce such a radical rearrangement of large streams as that which inaugurated Triassic deposition. This conclusion is perhaps the most important result of the present study, for it appears to verify the statement of Davis[1] that the Atlantic slope was reduced to a peneplain before the deposition of the Triassic sediments. In order to permit the formation of such longitudinal streams, the peneplain must have been practically continuous along the axis of the western fold, and hence today must be at an altitude at least equal to that of the main summits which cross the line.

(6) UTILITY OF THE STUDY OF DRAINAGE FEATURES.

It now remains but to add a word concerning the utility of this study. If the writer has succeeded in establishing the proposition that streams suffer modifications during crustal movements, no one can deny that a careful study of such modifications is extremely important in determining the principal movements in recent geologic ages. If it will do that, it is practically as efficient as the study of physiographic forms. The writer does not wish to be understood as advocating the replacement of the study of physiographic forms by the study of drainage forms, but rather to use the two in conjunction; in other words, to study the forms assumed by the instruments of erosion at the same time that we are studying the land forms produced by these same instruments—the streams. The results cannot be at variance and the studies will be a mutual advantage, one to the other.

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[1] The Geological Dates of Origin of Certain Topographic Forms on the Atlantic Slope of the United States, by W. M. Davis, Bulletin Geological Soc. Am., Vol. II. p. 549.